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Rheological study and valorization of waste sludge from wastewater treatment plants in the dredging operation of hydraulic dams

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Abstract

The wastewater resulting from various urban activities cannot be directly released back to natural environment because they contain various pollutants, including organics and minerals causing potential various types of diseases. Instead, wastewater must be purified prior to its release, which leads the production of waste sludge. A large quantity is produced from a wastewater in the purifications plants. An activated treatment of sewage wastewater also results in the generation of a considerable amount of excess sludge. This sludge must be disposed of safely. Commonly used disposal practices comprise of incineration, landfilling and application. The cost for sludge treatment is highly dependent on the volume and water content of the produced waste sludge. Treatment and disposal of an excess sludge in a biological wastewater treatment system requires a very high cost which accounts for approximately 35–60% of the whole operation cost of a wastewater treatment. In this study we propose a technique less expensive and more convenient. This technique is based on the use of sludge to reduce the loads losses during the dredging operation of hydraulic dams. The rheological study of mixtures of mud of dam and sludge from purifications plants showed a reduction of the yield stress of mud of dam up to 95%. Therefore the use of sludge from purifications plants during the dredging operation of dams facilitates the transport of sludge of dam.

Keywords: Dam, dredging operation, mixture, mud, sludge, rheological study, yield stress.

Nomenclature

Ea	Energy of activation for viscosity
SM	dry matter of waste sludge
T	temperature

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$\dot{\gamma}$	shear rate
τ	shear stress
τ_0	Yield stress
η_B	Bingham viscosity
η_{lim}	limiting viscosity

1. Introduction

The treatment of wastewater in the purifications plants generally leads to the formation of large quantity of sludge. These occur at the exit in a purification plant as a high concentrated viscous fluid. The sludge production has environmental risks. It is then necessary to find solutions to extract the sludge from purifications plants and to use it in different areas such as soil fertility, production of energy after calcinations and in the field of civil engineering (base coat for roads). These procedures are very expensive. For example the cost of disposing of excess sludge represents 60% of the cost of operating a purification plant in Europe [1]. The method of disposal of sludge by biological treatment is also high, about 35% to 60% of the cost of operating a purification plant [2].

A simpler technique is the use of sludge on agricultural land but this technique is very limited in Algeria**.**

In addition, conventional disposal methods of landfill or incineration cause pollution problems and an installation of incineration is quite expensive. However, this technique reduces the volume and mass of excess sludge. Several studies have focused on physical, chemical and biological processes in order to reduce sludge production, such as mechanical treatment using ultrasound [3,4], chemical treatment by ozone [5,6] acid or alkali [7] and biological hydrolysis without addition of enzymes. The ozone treatment is generally higher compared to physical treatment. Some researchers have combined treatment with ozone and biological treatment to minimize sludge production [8,9].

In this study we propose a less expensive and more convenient technique based on the use of sludge of purification plant as a means to reduce the load losses during the dredging operation of hydraulic dams to facilitate the transport of mud of dams to storage location.

2. Materials and methods

2.1. Sample preparation

2.1.1. The waste sludge from wastewater treatment plants

The waste sludge used in this study was recovered from the drying beds of sewage sludge from wastewater treatment plant of mascara Algeria as a powder. The sludge was dried in an oven during 24 hours at 40°C for dehydration, then crushed and pass away a sieve of 80 µm.

2.1.2 Preparation of sludge samples

The method of preparation has a great influence on the final state of suspension and then on the rheological behavior. An identical experimental procedure was therefore used for the preparation of all suspensions. First, sludge powder was dispersed in the required amount of distilled water in order to obtain two sludge suspensions (mass concentration equal to 23 and 28 wt %). Homogenization was obtained by continuous mechanical agitation during 24 h at ambient conditions.

2.1.3. The mud of dam

The mud used in this study was recovered in the discharge area of Dam Fergoug located in the region Perregaux (west Algeria). This dam is the first having been dredging in Algeria from 1986 to 1989 with over 10 million m^3 of dredged mud. This dredging was carried out with floating suction dredge extruders. Sediment (vases) are sucked into the dredge and discharged through a pipeline consisting of a floating and a fixed part of several hundred meters in length.

2.1.4. Preparation of mixtures

To study the effect of the addition of sludge on the rheological properties of mud suspension of dam two suspension of mud of dam were prepared (40% wt and 45 % wt). The mixtures of water-waste sludge-mud of dam were prepared by adding the powder of waste sludge in the mud of dam and then by adding a fixed volume of water. Homogenization was obtained by continuous mechanical stirring during 24 h at ambient conditions (Fig.1).

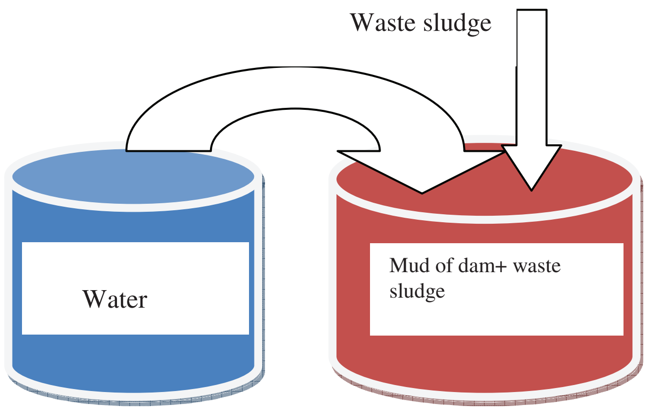

Fig.1. Preparation of mixtures

2.2. Rheometer used

The rheological measurements were preformed on a controlled stress rheometer MARS II from Thermo-Fischer, equipped with a cone and plate geometry (diameter: 35 mm; angle: 2 degree; gap: 104 μm). In order to prevent changes in composition during measurements due to water evaporation, a solvent trap was placed around the measuring device.

2.3. Experimental procedures

2.3.1. Effect of the temperature in rheological behavior of sludge of purifications plants

Sludge suspensions are known to be strongly thixotropic materials [10, 11, 12]. In order to avoid any memory effect, the sample was presheared at a constant shear rate 760 s^{-1} during 60 s. After this preshearing, the sample was kept at rest during 600 s prior to measurements in order to allow the material to recover, at least partially, its initial structure. The imposed shear stress range depends on the mass concentration of sludge [13, 14]. For the sludge mass concentration equal 23 wt% , a ramp of 0.2 Pa to 120 Pa during 600 s has been applied, for sludge mass concentration equal 28.5 % wt, a ramp of 0.2 Pa to 300 Pa during 600 s has been applied. The experiments were performed at different temperature between 5°C and 30°C.

In order to investigate the reproducibility of results, two replicates were made for most of the experiments.

3. Results and discussion

3.1. Effect of the temperature in rheological behavior of sludge

3.1.1. Typical rheogram of the sludge of purifications plants

The shear rate dependence of the shear stress for the two sludge samples (Fig.1 and 2) clearly shows a non Newtonian behavior after a small yield stress at each temperature (5°C to 30°C). When the shear rate is increased, the corresponding apparent viscosity (see inset Fig.1 and 2) decreases rapidly from a rather high value toward a constant value called the limiting viscosity value (η_{Lim}) at a high shear rate. The flow data measurements were fitted to the classical Herschel-Bulkley model

$$\tau = \tau_0 + K\dot{\gamma}^n \qquad (1)$$

where τ_0 is the yield stress in Pa, K the consistency index in Pa.s^n and n is the flow index.
Below the yield stress the granular exhibit solid-like characteristic, i.e., it stores energy at small strains and does not level out under the influence of gravity to form a flat surface. This features very important in design and quality assessment for sludge [15].

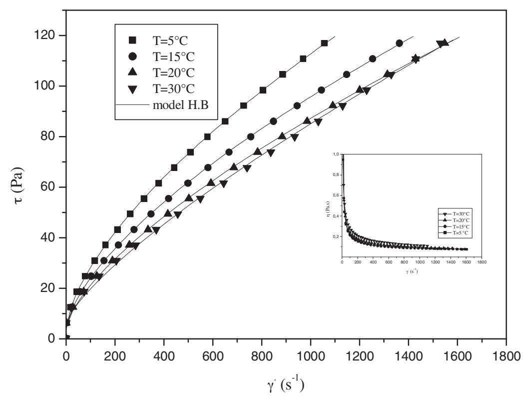

Fig.2. Shear stress as a function of shear rate at different temperatures (mass concentration 23 % wt of sludge of purifications plants). The solid lines correspond to the curve fitting to Eq.1.

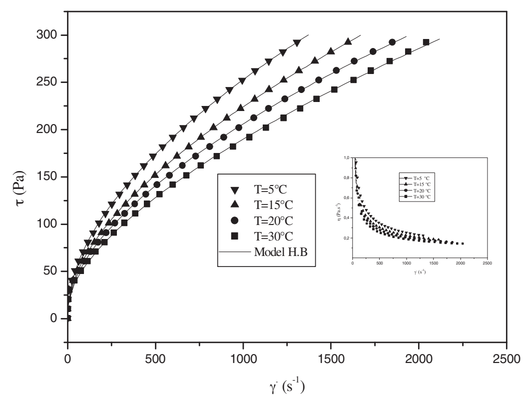

Fig.3. Shear stress as a function of shear rate at different temperatures (mass concentration 28.5 % wt of sludge of purifications plants). The solid lines correspond to the curve fitting to Eq.1.

The fitted parameters of the Herschel-Bukley model (Table 1) show an increase of both the yield stress and the flow index with increasing of temperature while the consistency index decrease.

Table.1. Herschel-Bukley parameters as a function temperature

Masse concentration %wt	T (°C)	τ_0 (Pa)	K (Pa.s$^{n)}$	n (-)	R^2
23 % wt	5	3.65±0.34	1.24±0.048	0.65±0.005	0.999
	15	4.02±0.38	0.95±0.043	0.66±0.006	0.999
	20	4.31±0.42	0.701±0.038	0.69±0.007	0.999
	30	6.24±0.68	0.39±0.040	0.76±0.013	0.998
28.5 % wt	5	9.79±0.52	4.92±0.104	0.56±0.002	0.999
	15	11.68±0.59	3.49±0.09	0.59±0.003	0.999
	20	11.92±0.65	3.21±0.096	0.59±0.003	0.999
	30	14.49±0.77	2.27±0.08	0.62±0.004	0.998

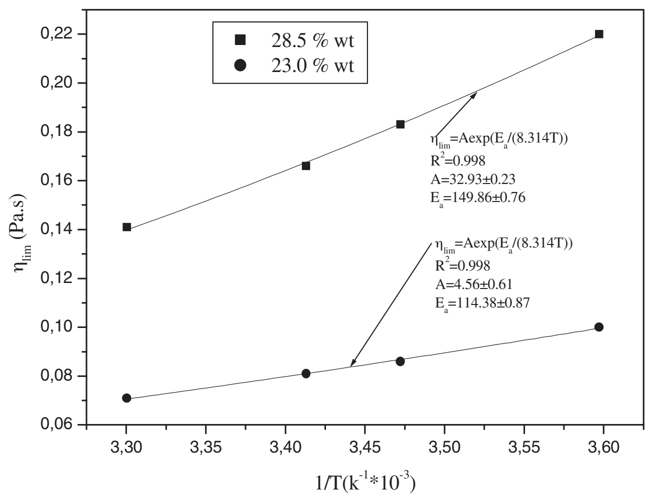

Fig.4. Limiting viscosity as a function of 1/T at masse concentration of 23 % wt and 28.5 % wt of sludge of purifications plants

The limiting viscosity value (η_{Lim}) computed from the results of Fig.1 and 2 decrease from 0.12 to 0.15 Pa s for the mass concentration of 28.5 % wt and from 0.1 to 0.071 Pa s for mass concentration of 23 % wt as the temperature was increased from 278 to 303 °K. This result is in agreement with those reported by Mikulasek [16] and Mu [17]. The thermal motion of particles is more important at a higher temperature, and then the network strength between particles is weakened, resulting in a decrease in viscosity. The temperature dependence of the limiting viscosity of the sludge could be described by an Arrhenius type equation (2) involving the absolute temperature (T), universal gas constant (R), energy of activation for viscosity (Ea) [18,19]:

$$\eta_{Lim} = A\ exp(-\frac{E_a}{RT}) \qquad (2)$$

3.2. Effect of the waste sludge in rheological behavior of mud of dam

As for the sludge samples, the shear rate dependence of the shear stress for the mixtures is well fitted by Herschel-Bukley model (Fig. 5 and 6).

As shown in Figs.7 and 8 the yield stress of mud can be decreased up to 95% by adding dry matter (SM) waste sludge. This decrease could be explained by a lower friction due to the presence of polymers in the waste sludge as suggested by [20, 21].

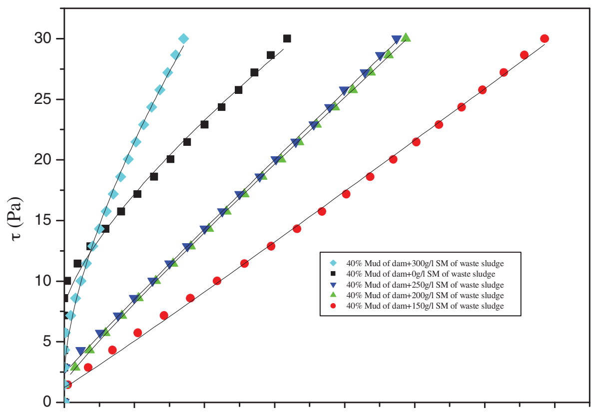

Fig.5. Effect of waste sludge on flow curve of mud of dam at 40 % wt

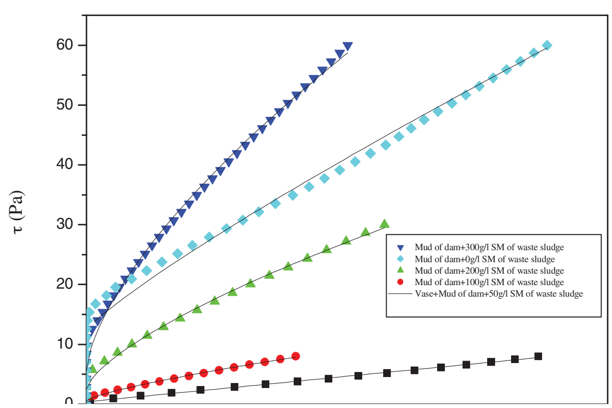

Fig.6. Effect of waste sludge on flow curve of mud of dam at 40 % wt

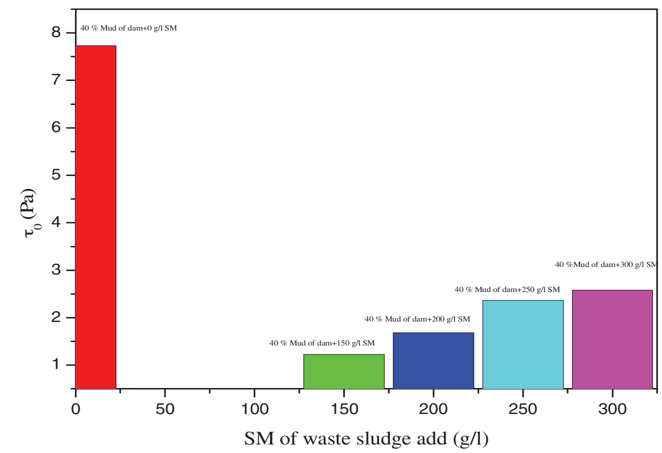

Fig.7. Evolution of yield stress of mud (mass concentration of mud equal 40% wt) as function of the added dry matter (SM) waste sludge

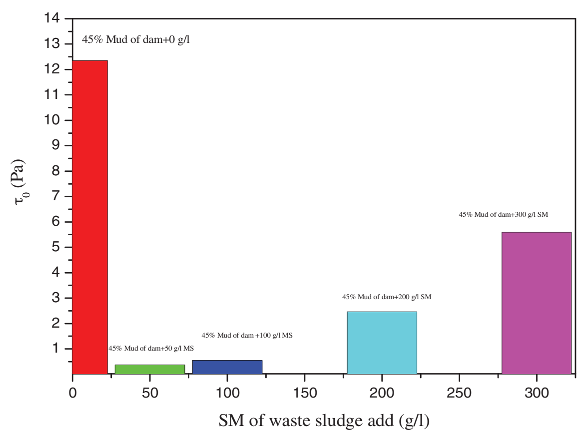

Fig.8. Evolution of yield stress of mud (mass concentration of mud equal 45% wt) as function of the the added dry matter (SM) waste sludge

4. Conclusion

In this study the temperature effect the non newtonian rheological behavior of residual sludge was first investigated. The flow curves were well fitted by the Herschel-Bulkley model. By increasing temperature, both the yield stress and the flow index increased while the consistency index decreased. The limiting viscosity at high shear rate of decreased with increasing temperature, and their relationship could be modeled by the Arrhenius equation.

It was then clearly demonstrated that the addition of waste sludge in mud of dam induced a decrease of the yield stress of mud of dam up to 95%. Therefore the use of sludge from purifications plants during the dredging operation of dams facilitates the transport of mud of dam.

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